

Extending $E = mc^2$

A Quantum Physics Extension of the Energy Equation

$$\text{From } E = \gamma mc^2 \text{ to } E = \gamma \left(mc^2 + \sum_i \kappa_i \Phi_i \right)$$

Jan Klein, 1 April 2026, Hannover, Germany - ORCID: [0009-0002-2951-995X](https://orcid.org/0009-0002-2951-995X)

Contact: janklein@engineer.com - Website: bix.pages.dev

Keywords: mass, energy, mass-energy equivalence, quantum field theory, QFT, philosophy of quantum field theory, Higgs mechanism, strong force, quantum vacuum, standard model, general relativity, Einstein, philosophy of physics, reductionism, emergence, ontic structural realism, conventionalism, special relativity, particle physics, vacuum energy, Yukawa coupling, gluon, confinement, binding energy, relational properties

Abstract

Einstein's equation $E = \gamma mc^2$ describes the energy of a body moving in empty space. Yet no physical body exists in empty space. Every particle moves through quantum fields: the Higgs field, the strong nuclear field, the electromagnetic field, the gravitational field, and quantum vacuum fluctuations. This paper asks a simple question: what happens to the energy equation when we include these fields? I present a generalized expression $E = \gamma(m_0c^2 + \sum_i \kappa_i \Phi_i)$ derived from the action principle. The sum runs over all fields that couple to the particle. I then examine the conceptual consequences. The extended equation suggests that what we call “mass” is not a primitive property but a summary of field interaction energies. I argue that this does not contradict Einstein but rather makes explicit an assumption in the original derivation: empty space. The paper concludes by discussing how quantum field theory already uses this structure (the Higgs mechanism, the proton mass from gluons) and why making it explicit matters for the philosophy of modern physics.

1. Introduction: Einstein's Empty Space

In 1905, Albert Einstein derived a relationship that would become the most famous equation in physics: $E = mc^2$. For a body in motion, he showed that the energy becomes $E = \gamma mc^2$, where $\gamma = 1/\sqrt{1 - v^2/c^2}$. The derivation assumed a body in empty space, free of external potentials or fields.

But no real body exists in empty space. Every particle moves through the gravitational field, the electromagnetic field, the Higgs field, the strong nuclear field, and the quantum vacuum. These fields contain energy. They interact with particles. They contribute to what we measure as mass. Should they not appear in the fundamental energy equation?

This paper does not claim that Einstein was wrong. Rather, it asks: what happens to the energy equation when we stop assuming empty space? I propose a minimal extension that includes field contributions while preserving the structure of Einstein's original formula. The extension is physically correct and consistent with modern quantum field theory. But my primary aim is not to derive new physics. It is to examine a conceptual question: **what does "mass" mean when we recognize that every body is always already embedded in fields?**

The paper proceeds as follows. Section 2 reviews Einstein's original equation and its conceptual assumptions. Section 3 introduces a first extension: adding a single field. Section 4 presents the complete expression summing over all known quantum fields, with a brief derivation from the action principle. Section 5 examines the philosophical implications. Section 6 shows that quantum field theory already uses this structure in concrete cases. Section 7 addresses objections. Section 8 concludes. A final reflection closes the paper.

2. The Original Equation: Mass as Intrinsic

Einstein's 1905 derivation considered a body at rest emitting two light pulses in opposite directions. By analyzing the motion of the body's center of mass, he concluded that the body's mass must decrease by $\mathbf{m} = \mathbf{E}/\mathbf{c}^2$. For a body in motion, the total energy becomes $\mathbf{E} = \gamma\mathbf{m}\mathbf{c}^2$.

Conceptually, this equation treats mass as an **intrinsic property** of the body. The body has a certain amount of "stuff" - mass - that determines its energy at rest and its inertia when moving. Fields and potentials do not appear. The body is assumed to be alone in the universe.

This assumption was reasonable in 1905. Quantum field theory did not exist. The Higgs mechanism was sixty years away. The strong nuclear force was unknown. Einstein could not have known that most of the proton's mass comes from gluon fields, not from intrinsic "stuff." Today, we know better. Every particle is constantly interacting with fields. The question is not whether fields contribute to energy - they do - but whether the original equation already accounts for them implicitly or needs to be extended.

3. A First Extension: Adding One Field

The simplest way to include a field is to add its interaction energy directly to the rest energy. For a particle at rest in a static potential Φ with coupling constant κ , the total energy is:

$$\mathbf{E} = \mathbf{m}\mathbf{c}^2 + \kappa\Phi$$

For a particle in motion, the Lorentz factor γ multiplies the entire expression because kinetic energy and field energy both transform the same way under Lorentz boosts (for scalar potentials):

$$\mathbf{E} = \gamma (\mathbf{m}c^2 + \kappa\Phi)$$

This preserves the relativistic dispersion relation and reduces to Einstein's equation when $\Phi = 0$.

Example: gravitational field. In the weak field limit of general relativity, a particle of mass $\mathbf{m}$ in a gravitational potential $\Phi_{\text{grav}} = -\mathbf{GM}/\mathbf{r}$ has energy:

$$\mathbf{E} = \gamma (\mathbf{m}c^2 + \mathbf{m}\Phi_{\text{grav}})$$

This matches the result derived from the Schwarzschild metric and is confirmed by GPS time dilation and Pound–Rebka experiments. Already at this stage, a conceptual shift occurs. Energy is no longer a property of the body alone. It is a property of the **body-field system**. The original equation treated the field as absent; the extended equation makes the field explicit.

4. The Complete Expression: All Quantum Fields

A particle is never immersed in just one field. It feels gravity, electromagnetism, the Higgs field, and the strong nuclear field. Each field has its own coupling strength and potential. Therefore, the complete expression sums over all fields:

$$\mathbf{E} = \gamma \left(\mathbf{m}_0c^2 + \sum_{\mathbf{i}} \kappa_{\mathbf{i}}(\mathbf{x}) \Phi_{\mathbf{i}}(\mathbf{x}) \right)$$

where: $\gamma = (1 - \mathbf{v}^2/c^2)^{-1/2}$ is the Lorentz factor, $\mathbf{m}_0$ is the bare (intrinsic) mass parameter, $\Phi_{\mathbf{i}}(\mathbf{x})$ is the potential associated with field $\mathbf{i}$, and $\kappa_{\mathbf{i}}(\mathbf{x})$ is the coupling function (may vary with position). The sum runs over all fields that couple to the particle: gravitational, electromagnetic, Higgs, strong, and any beyond-Standard-Model fields.

Derivation from the action principle

Start from the action for a point particle coupled to multiple scalar potentials:

$$S = \int d\tau \left[-m_0 c^2 - \sum_i \kappa_i(\mathbf{x}) \Phi_i(\mathbf{x}) \right]$$

where $d\tau = dt/\gamma$ is proper time. Each term $\kappa_i \Phi_i$ is Lorentz invariant if Φ_i is a scalar potential (for vector/tensor fields, the coupling involves contractions; the sum generalizes accordingly). For static fields, time-translation invariance holds, and Noether's theorem yields a conserved energy. Performing the Legendre transformation gives the Hamiltonian, which in the particle's rest frame becomes the expression above.

Explicit form for known fields

$$E = \gamma \left(m_0 c^2 + \kappa_{\text{grav}} \Phi_{\text{grav}} + \kappa_{\text{EM}} \Phi_{\text{EM}} + \kappa_{\text{Higgs}} \Phi_{\text{Higgs}} + \kappa_{\text{strong}} \Phi_{\text{strong}} + \dots \right)$$

Field	Coupling κ	Potential Φ	Contribution
Gravity	gravitational mass $\mathbf{m}$	$-GM/r$	$\mathbf{m} \Phi_{\text{grav}}$
Electromagnetism	electric charge $\mathbf{q}$	electrostatic potential ϕ	$\mathbf{q} \phi$
Higgs	Yukawa coupling $\mathbf{y}$	vacuum expectation value $\mathbf{v} \approx \mathbf{246 \text{ GeV}}$	$\mathbf{y} \mathbf{v}$ (gives fermion masses)
Strong (confinement)	color factor $\mathbf{g_s} \cdot \mathbf{C}$	effective confining potential	gluon field energy (~99% of proton mass)

Reduction to Einstein: In the absence of all fields ($\Phi_i = 0$), the expression reduces to $E = \gamma m_0 c^2$. For a body at rest: $E = m_0 c^2$. Einstein's original equation is recovered as a special case.

5. What Does This Tell Us About Mass?

The extended equation is physically correct. But its significance is conceptual. It forces us to reexamine what we mean by “mass.”

5.1 Mass as a summary, not a primitive

Every term in the sum $\sum_i \kappa_i \Phi_i$ is a field interaction energy. The proton's mass is $938 \text{ MeV}/c^2$. Of this, only about $9 \text{ MeV}/c^2$ comes from the rest masses of its constituent quarks. The remaining $929 \text{ MeV}/c^2$ comes from the strong field energy - gluons and their interactions. The electron's

mass is entirely from the Higgs field; the bare mass $\mathbf{m}_0$ for electrons is zero before electroweak symmetry breaking. What we call “mass” is therefore a **summary** of field coupling energies.

5.2 Three philosophical interpretations

Reductionism. Mass may be *nothing but* the sum of field couplings (plus a possible irreducible $\mathbf{m}_0$). For elementary fermions, the Higgs mechanism achieves exactly this reduction: $\mathbf{m}_0 = 0$. For composite particles, 99% of the proton mass is strong field energy. Ontological reduction of mass to field energies is plausible.

Structural realism. Mass is revealed as a **relational property**. A particle does not have mass in isolation. It has mass only relative to the fields to which it couples. Change the Higgs vacuum expectation value, and the electron’s mass changes. Remove the strong field, and the proton’s mass drops to 9 MeV/ c^2 . This aligns with ontic structural realism (Ladyman, 1998; Ladyman & Ross, 2007).

Conventionalism. The split between $\mathbf{m}_0$ and $\sum_i \kappa_i \Phi_i$ is not empirically fixed. One could redefine $\mathbf{m}_0$ to absorb some field terms. The physically measurable quantity is the total sum, not its partition. This echoes Poincaré’s conventionalism about geometry.

6. Case Studies from Quantum Physics

Electron mass. In the Standard Model, the electron’s mass comes entirely from the Higgs mechanism: $\mathbf{m}_e c^2 = \kappa_{\text{Higgs}} \Phi_{\text{Higgs}}$.

Proton mass. $\mathbf{m}_p c^2 = \sum \mathbf{m}_q c^2 + \kappa_{\text{strong}} \Phi_{\text{strong}}$ (9 MeV from quarks + 929 MeV from gluon field).

Nuclear binding energy. Negative $\kappa_{\text{strong}} \Phi_{\text{strong}}$ in bound states reduces total mass.

Particle creation in colliders. Energy redistributes into new particles, each with its own $\mathbf{m}_0 c^2 + \sum_i \kappa_i \Phi_i$.

7. Objections and Replies

Objection 1: “This is just physics, not philosophy.”

Reply: The question “What is mass?” is conceptual. Physicists measure mass; they rarely ask whether mass is primitive or relational. That is philosophy of science.

Objection 2: “Einstein already included fields via $\mathbf{E} = \sqrt{\mathbf{p}^2 c^2 + \mathbf{m}^2 c^4}$.”

Reply: That equation includes kinetic and rest energy, not potential energies from external fields. The extended equation accounts for potentials explicitly.

Objection 3: “Your Φ_i are not Lorentz invariant for vector fields.”

Reply: The action can include Lorentz-invariant couplings like $\mathbf{q} \mathbf{A}_\mu d\mathbf{x}^\mu / d\tau$. The philosophical point remains unchanged.

Objection 4: “ $\mathbf{m}_0$ is still primitive.”

Reply: For elementary fermions, $\mathbf{m}_0 = \mathbf{0}$ before symmetry breaking; the Higgs mechanism removes the primitive mass.

Objection 5: “Your equation is trivial.”

Reply: Triviality is not an objection. It is a sign of conceptual clarity. The point is to make explicit what was implicit.

8. Conclusion

Einstein taught us that mass and energy are one: $\mathbf{E} = \gamma \mathbf{m} \mathbf{c}^2$. But he considered a body in empty space. The universe is not empty. It is filled with quantum fields — Higgs, strong, electromagnetic, gravitational - each carrying energy and interacting with every particle. We have presented a minimal extension:

$$\mathbf{E} = \gamma \mathbf{m} \mathbf{c}^2 \rightarrow \gamma (\mathbf{m} \mathbf{c}^2 + \kappa \Phi) \rightarrow \gamma \left(\mathbf{m}_0 \mathbf{c}^2 + \sum_i \kappa_i \Phi_i \right)$$

The final expression reduces to Einstein’s when fields are absent, explains the origin of mass in the Higgs and strong fields, and unifies all field contributions under a single structure. Philosophically, **mass is not a primitive property but a summary of a particle’s interactions with the fields that fill all of reality**. Whether this amounts to reductionism, structural realism, or conventionalism remains an open debate - but the equation provides a concrete framework for that debate.

Einstein’s $\mathbf{E} = \mathbf{m} \mathbf{c}^2$ was a special case of a more general principle: energy is always energy-of-body-plus-fields. Making fields explicit is not a correction. It is a completion.

Final Reflection

What began as a simple question - *should fields appear in the energy equation?* - led to an extended formalism that reveals mass as a summary of field interactions. The progression

$$\mathbf{E} = \gamma \mathbf{m} \mathbf{c}^2 \rightarrow \gamma (\mathbf{m} \mathbf{c}^2 + \kappa \Phi) \rightarrow \gamma \left(\mathbf{m}_0 \mathbf{c}^2 + \sum_i \kappa_i \Phi_i \right)$$

is mathematically minimal but conceptually significant. It reminds us that physics does not occur in empty space, and that what we call “mass” is never isolated from the fields that fill reality.

In teaching, we often present $\mathbf{E} = \mathbf{m} \mathbf{c}^2$ as a self-contained truth. Perhaps we should also teach that it is a special case - a beautiful one, but one that assumes the very emptiness our universe

does not have. Making fields explicit is not a correction of Einstein but a completion of his insight.

This work was driven by a simple love for understanding. I hope it invites others to ask not only *what* the equations say, but *what they assume* - and what becomes visible when those assumptions are lifted.

Acknowledgments

I thank my mother for teaching me patience, and I acknowledge the intellectual tradition that connects physics and philosophy. Thanks to Allah for the love to research. All errors are my own.

References

- Einstein, A. (1905). On the Electrodynamics of Moving Bodies. *Annalen der Physik*, 17, 36-65.
- Einstein, A. (1905). Does the Inertia of a Body Depend Upon Its Energy Content? *Annalen der Physik*, 18, 639–641.
- Pound, R. V., & Rebka, G. A. (1960). Apparent Weight of Photons. *Physical Review Letters*, 4, 337–341.
- Higgs, P. W. (1964). Broken Symmetries and the Masses of Gauge Bosons. *Physical Review Letters*, 13, 508–509.
- Wilczek, F. (1999). Mass Without Mass I: Most of Matter. *Physics Today*, 52(11), 11–13.
- Ashby, N. (2003). Relativity in the Global Positioning System. *Living Reviews in Relativity*, 6, 1.
- Ladyman, J. (1998). What is Structural Realism? *Studies in History and Philosophy of Science*, 29(3), 409–424.
- Ladyman, J., & Ross, D. (2007). *Every Thing Must Go: Metaphysics Naturalized*. Oxford University Press.
- Poincaré, H. (1902). *Science and Hypothesis*. Walter Scott Publishing.
- Peskin, M. E., & Schroeder, D. V. (1995). *An Introduction to Quantum Field Theory*. Westview Press.
- Klein, J. (2026). *On the Energy of Moving Bodies in the Presence of Quantum Fields*. bix.pages.dev.

URL of this document: <https://bix.pages.dev/Extending-E-mc2>

Licensed under Creative Commons Attribution 4.0 International